

THE PERFORMANCE ANALYSIS OF FUNCTIONAL AND RECONFIGURED LAYOUT BY MINIMISING INTERCELLULAR MOVEMENT: A CASE STUDY OF INDIAN SME

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Abstract: Group technology (GT) utilizes a philosophy that involves grouping of components having similar manufacturing and design attributes, known as part families (PF). In a job shop (JS) products are processed in smaller batches and with the products are changed the new processing sequence increases /changes material handling within JS. Hence to reduce material handling machines need to be arranged in cells so that most of family members can be manufactured within the cell referred as Cellular manufacturing (CM), which is one of the application of GT. The main goal of this research work is to present a performance comparison of functional JS of small medium enterprise (SME) with the objective to decrease intracellular movement of parts using newly developed approach. Effectiveness of reconfigured JS due to the proposed method and the functional layout is compared using six well known measures.

Keywords: cellular layout, machine – component cells, group technology, material handling movement.

INTRODUCTION

Group technology (GT) utilizes the concept of commonality between production processes and parts to be processed in a manufacturing unit (MU). It is a philosophy that involves recognizing and grouping components having similar manufacturing and design attributes known as part families (PF) in order to achieve the benefit of producing them with reduced work-in-process inventory, material handling cost, throughput time, etc. Cellular manufacturing (CM) is one of the application of GT principles to manufacturing. For each PF, required machines are arranged together to form a machine cell or a manufacturing cell, and most family members can be manufactured within the cell. This kind of layout design problem is referred to as the cellular manufacturing problem (CMP). CM emerged as a production strategy capable of solving the problems of complexity and long manufacturing lead times in batch production. The fundamental problem in CM is the formation of product families and machine cells.

One of the key reason that a manufacturing unit performs well when the facilities are arranged scientifically. Always the back tracking moves must be minimised. The study presented here applies cell formation technique based on machine – component processing association to the functional machine arrangement in a JS of a small medium enterprise (SMEs) in India to minimize the material handling movement. The outcome of study is formation of machine – component cells as the initial solution. Thereafter the initial solution is modified suitably and other performance parameters along with material handling movements are checked. The study clearly

indicates the group efficacy and efficiency measures are improved due to proposed methodology remarkably. The method suggested in the proposed work can be easily used by the leading practitioners.

LITERATURE REVIEW

Number of papers are published on the cell formation techniques. Some of the published work related to the cell formation is reviewed here. Adil et al.¹ have proposed method based on non linear programming for cell formation. Zhao and Wu² minimized parts holding cost and intercellular movements with good balance of machine and cell utilization. Kim et al.³ have proposed a heuristic technique for cell formation problem. The objective was to minimize intercellular movements and machine workload imbalance. Hachicha et al.⁴ have proposed a correlation analysis approach of cell formation in view of minimizing the total processing time outside the cells, including production parameters. The approach is two phased i.e. grouping based on correlation in first phase and Principal Component Analysis (PCA) used for cluster analysis to form machine groups and part families at the same time. Megala et al.⁵ proposed an ant colony algorithm for cell-formation. The objective was to maximize the group efficacy. Praveen et al.⁶ have suggested four fold new approach for cell formation that amalgamate machine grouping and layout design regardless of initial part-family formation. Co and Egibelu⁷ have proposed method of cell formation for suitable for the changes in product demand in volume or design with time. The cells are referred as virtual cellular manufacturing system. Sofianopoulou⁸ proposed

a genetic algorithm approach with the aim of least interaction between cells and also accounting for sequences of machining. Manzini et al.⁹ have proposed similarity coefficient based method based on a threshold value which was obtained through percentile-based cut value. Jayachitra and Prasad¹⁰ have also compared the performance of existing and suggested layout through a simulation technique. The virtual model representing the industry is created through the use of WITNESS 2006. The results proved the suggested virtual layout to be cost effective. Shahrul et al.¹¹ have also illustrated the effect of design of layout through checking the performance of all the three cellular, flow line, and job shop layout. The results shown the performance of flow line, job shop and cellular layout is changed due to layout design. Kumar et al.¹² have suggested heuristic method for the issues associated to layout design. The method considers unidirectional flow of material, avoiding back-tracking and emphasizing the distance traveled by the components to be minimum. Ying et al.¹³, have suggested, a simulated annealing-based meta-heuristic technique which considers variable neighbourhood to form part-machine cells. The results were obtained through experimentation on real life data sets. Mahdavi et al.¹⁴ have suggested the methodology for formation of virtual cells by considering in variations in part volume and in component mix for different time periods. The worker flexibility was also considered. Farahani and Hosseini¹⁵ have proposed an efficient algorithm for machine– component problems aiming for improving grouping efficacy. Use of information from similarity of processing of components is made for forming the part families. Mathur et al.¹⁶ have suggested improvement in productivity in a SME using scheduling heuristic via case study. Elbenani and Ferland¹⁷ have proposed method based on a linear binary programming formulation which provides quality results. Solutions generated by the proposed method were compared with that of obtained by other researchers from literature. Shahram et al.¹⁸ investigated effects of ambiguity in exact demand of products on the layout in a cellular manufacturing system. The focus of study was minimization of cost of material handling within and outside the cells. The use of optimization software was done for the same. Saravanan and Arulkumar¹⁹ minimized the intercellular movement of parts by comparing two methods named as Genetic Algorithm (GA) and Simulated Annealing Algorithm (SAA). The emphasis was also given to the parts to be manufactured in large volume, minimum back tracking of parts and parts requiring more safety. Masmoudi and Hachicha²⁰ have suggested that the cell formation technique without due consideration to real life situations are

unsuitable for implementation. Hence by providing importance to parameters like maximum number of machines in a cell and cost associated with alternative actions to eliminate the exceptional elements (EE) so as to form better machine-component cells was demonstrated. However none of the studies have revealed clear usage of their methods for the easier adoption by manufacturer.

The study presented here is to provide solution for enhancing the productivity in a SME through reconfiguration of the functional layout of machines through newly developed algorithm for the formation of machine- component cells. Various steps involved in the study are described in subsequent sections of this paper.

AIM OF THE STUDY

Determining the scope of improvement in productivity of a JS through conversion into a cellular layout by application of newly developed approach.

THE DETAILS OF THE STUDY

The study is done at SME named ‘M/s Kinetic Gears’. The initial incidence matrix of machine and components is developed through their association known from route sheets of components. For the sake of study the number of components, machines considered are 17 and 21 respectively. Some work stations are manual such as deburring, cleaning of components, packing etc. Some of the components need heat treatments and machining which are carried out at M/s Heat Treat Well and M/s Garuda Yantra Nirmiti. (Another nearby units owned by same owner) by transporting manually from ‘M/s Kinetic Gears’ so as to meet the master production schedule. The quantity to be produced is decided as per the orders received from the clients. The manufacturing is done as per job shop or in batches of suitable size. Names of the jobs being processed and undertaken processes are shown in Table 1 and 2 respectively. These components are manufactured for the automotive units.

METHODOLOGY

The stepwise procedure applied for determination of cells formed due to proposed method is elaborated in this section.

Step I: The development of incidence matrix

The initial incidence matrix showing the machining requirements of machine and components is developed through their association known from route sheets of components. The developed incidence matrix is shown in Fig.1.

For each process ‘1’ is entered in the matrix for associated component and machine link. If component is not processed by certain machine

then it is denoted by '0' in the matrix. The size of relationship matrix is $[n \times m]$, if n is no. of components and m is no. of machines.

Table 1. List of components.

S. no.	Name of the component
1	Detend plunger
2	Washer Output flange
3	Split Ring
4	Selector plate
5	Driver plate
6	Out put flange
7	Elbow
8	Tachopinion
9	Speedo shaft
10	Seat check valve
11	Relief Valve Spring Housing.
12	Joint Pin
13	Pin Shackle Rear
14	Constant Mesh
15	Driver
16	Washer
17	Speedometer Worm

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00000000100100000
00000001100101000
00000001000001000
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00000010000000000
00000010000000000
000000100000000010
0000001000000000100
1111111111101011
1111111111111111
00111000100000001
10100000100100000
11111001111110111
11000110000000000
11111110000000000
11100111000001101
    
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Figure 1. The Incidence matrix (after Step I).

Step II:

Set $i = 0$, i.e. no component is in process.

Set $i = i+1$, identify the machine/machines which visit/visits the 'i' th component. If the link is established (i.e. the entry of one for (i+1)th component) calculate the coefficient of relationship

$$\text{defined as, } R_{ij} = \frac{NCE_{ij}}{TME_{ij}}$$

where, NCE_{ij} = No. of '1's' common entries for i^{th} component and j^{th} machine.

TME_{ij} = Total no. of non-zero entries for i^{th} component and j^{th} machine.

If $R_{ij} = 1$, i^{th} component visits j^{th} machine only and vice versa.

$R_{ij} = 0$, i^{th} component do not visit the j^{th} machine at all.

Such R_{ij} values for each non-zero entries in incidence matrix are calculated.

Table 2. Undertaken processes.

S. no.	Name of process /workstation
1	Gear rolling
2	Tempering
3	Straightening
4	Quenching
5	Cleaning by hot water
6	Binding by wire
7	Turret lathe
8	Deburring
9	Gear hobbing
10	Furnace
11	Band saw machine
12	Phosphating
13	Broaching
14	Packing and dispatch
15	Inspection
16	Milling
17	Grinding
18	Heat treatment
19	Drilling
20	Punching machine
21	Turning on CNC lathe.

Step III:

All the values of R_{ij} calculated in step 2 are entered in a matrix of $[R_{ij}]$, for which no. of rows (i) = n and no. of columns (j) = m

Step IV:

(a) Select the maximum value of R_{ij} from the matrix $[R_{ij}]$, and select the corresponding component-machine link, in case of equal values of R_{ij} coefficient select one of them arbitrarily.

(b) Draw a horizontal and vertical line through selected value of R_{ij} . Identify the non-zero entries on the vertical line. Select the next maximum value of R_{ij} in the vertical line. In case of tie between maximum value and next maximum value (or between next maximum values) select any one arbitrarily. Draw a horizontal line passing through selected next maximum value and select the associated component. Link this component to link selected in sub step 'a'.

In case of all zero values on vertical line omit this step and proceed as given below.

(c) Select the next maximum value of R_{ij} from the non-zero R_{ij} values on the horizontal line of latest selected component. In case of tie select any one value of R_{ij} arbitrarily. Draw a vertical line passing through the latest selected R_{ij} value and select the associated machine. Link the machine

selected with latest link selected in sub step 'a' /'b' whichever selected later.

Go on selecting the machine and component till linkage is continued but once selected machine or component should not be selected again.

If first link breaks before selecting all component/machines indicates first cell or s cell formed consisting of selected machines/components and repeat the procedure from sub step 'a' after formation of each cell and there is no intercellular movement of components.

If a continuous link, consisting of all machine/s and component/s is obtained than it indicates that cells can't be separated due to presence of exceptional component/s.

Step V:

Reposition the components column wise and machines row wise in a matrix as obtained during selection process or cell formation process. This matrix is called as resulting matrix. Make the entries of 'one's' of each corresponding component-machines from the relationship matrix obtained in step 1.

The output is expected to form a block diagonalized matrix if exceptional components are absent.

Step VI:

The formed machine – components cells, associated analysis and resulting matrix obtained after the step II as a resulting file is shown in Fig. 2 along with initial incidence matrix.

Step VII:

Checking grouping efficiency and other performance measures.

In view of results analysis following performance measures are used.

i) Total number of 'Exceptional Elements', EE which leads to the intercellular movements. In above example the EE are 16, which is also much higher and also grouping efficiency is 0.5955 % and hence in order to minimize the intercellular movements. The following solution is suggested. Keeping only 11th, 10th, 12th machines outside the cells, only one cell of all the other machines and parts may be formed. Which reduces outside entries of one's to 4. The modified suggested solution is given in Fig. 3.

The other performance measures suggested in literature are also checked with respect to the modified solution and there values are calculated in this section.

ii) Grouping efficiency: Chandrasekharan and Rajagopalan²¹ have proposed the grouping efficiency measure for the first time. The grouping efficiency η is the average of η_1 and η_2 .

$$\eta_1 = \frac{e_d}{\sum_{i=1}^c M_i N_i}$$

$$\eta_2 = 1 - \frac{e_o}{n x m - \sum_{i=1}^c M_i N_i}$$

$$\eta = q \eta_1 + (1 - q) \eta_2$$

Where, n is total no. of parts

m is total no. of machines.

M_i the number of machines in the i-th cell .

N_i the number of parts in the i-th cell.

e_d the number of '1' in the diagonal blocks.

e_o the number of '1' in the off diagonal blocks.

q the weighting factor. ($0 \leq q \leq 1$)

C the number of cells.

Here, η_1 is the measure for the within group utilization, implies how much the machines of each cell handle the parts of the corresponding family. And the η_2 implies about the least inter cell movement of the parts and how few exceptional parts exists. These measures reflect different aspects of the grouping effectiveness. The η is the measure of grouping efficiency. Larger the value of the efficiency the better is the grouping effectiveness becomes.

The value of η ranges between 0 and 1. For the purpose of numerical analysis the weighting factor, q, is taken as 0.5 implies both machine utilization and number of exceptional elements are equally important. The values for the solution suggested in figure 3.0 are $\eta_1 = 0.333$, $\eta_2 = 0.921$ and $\eta = 62.7$ %.

iii) Group efficacy: Chandrasekharan and Rajagopalan²² have proposed the grouping efficacy, τ as,

$$\tau = \frac{1 - \phi}{1 + \phi}$$

where, ϕ = the ratio of number of exceptional elements to the total number of elements.

ϕ = the ratio of 0 s (blank spaces) in the formed cell block to the total number of elements.

Therefore, $\phi = 4/106 = 0.0377$

$$\phi = 204/106 = 1.924$$

$$0.9623/2.294 = 0.4194$$

iv) Grouping measure: Machine utilization index (η_g) was proposed by Miltenburg and Zhang²³. This measure gives the machine utilization in the cell.

$$\eta_g = \eta_u - \eta_m$$

where $\eta_u = e_d / e_{d+v} = 102/102+(306-102) = 0.33$
'v' is voids in the cell.

		Parts																	
		o	b	a	c	q	e	d	j	m	k	h	n	i	l	g	f	p	
Machines	13	1															1		
	21	1	1	1	1	1					1	1			1	1			
	19		1	1												1	1		
	17			1	1									1	1				
	16				1	1	1	1						1					
	18	1	1	1	1	1	1	1	1	1	1	1		1	1			1	
	20		1	1	1		1	1								1	1		
	15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	14		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	6								1	1	1								1
	2									1									
	4									1	1								1
	5					1			1	1	1				1				1
	9											1	1						
	1													1					
	8											1	1	1	1				
	7													1	1				
	3														1				
	11																1		
10																1			
12																	1	1	

Figure 3. The modified solution.

$\eta_m = 1 - e_{d/o} = 1 - 102/106 = 0.0377$
 'o' is total number of 1s in incidence matrix .

Therefore $\eta_g = 0.33 - 0.0377 = 0.2977$

v) Grouping capability index (GCI):

$GCI = 1 - e/o$

where, *e* is number of exceptional elements in resulting matrix.
o is total number of operations in the matrix.

Hsu²⁴ excluded entries of 0s from the calculation of group efficacy and efficiency

$GCI = 1 - 4/106 = 0.9623$

vi) Grouping index (GI): Nair and Narendran²⁵ proposed a new measure of performance. The voids and exceptional elements were given same importance and considering the block digonalised area of solution they combined the above three

measures and proposed a weighting factor, correction factor, and block diagonal space.

$$\gamma = \frac{1-\alpha}{1+\alpha}$$

where, $\alpha = \frac{qv + (1-q)(e-A)}{B}$

B is block diagonalised area.

$A=0$ for $e \leq B$

$A=e-B$ for $e > B$

The values of α and γ lie between 0 and 1.

Assuming the weighting factor $q = 0.5$

$$\alpha = \frac{0.5 \times 204 + (1-0.5)(4-0)}{306} = 0.3398$$

$$\gamma = \frac{1-0.3398}{1+0.3398} = 0.4927$$

The functional arrangement of machines and components in the plant is shown in Fig. 4. All the above performance measures are checked for functional arrangement in the plant as well. The shaded area of matrix in Fig. 4 depicts operations which are conducted in the premises of ‘M/s Kinetic Gears’ and non – shaded portion of matrix indicates operations which are carried outside the ‘M/s Kinetic gears premises through manual transportation of components.

		Parts																	
		a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	
Machines	2													1					
	7									1			1						
	12						1										1		
	1														1				
	3												1						
	4												1	1			1		
	5											1	1	1	1		1	1	
	6											1	1		1		1		
	10							1											
	13						1									1			
	14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	18	1	1	1	1	1			1	1	1	1	1	1	1		1	1	1
	21	1	1	1				1	1			1	1			1		1	
	20	1	1	1	1	1	1	1											
	19	1	1				1	1											
	17	1		1						1				1					
	16			1	1	1				1									1
	15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11							1												
8								1	1				1		1				
9								1							1				

Figure 4. The existing arrangement of machines at ‘M/s Kinetic Gears’.

i. Total number of ‘Exceptional Elements’, EE , from the Fig. 4 is 53 (The number of 1s in the non shaded area of matrix in Fig. 4) .

ii. Grouping efficiency:

$$\eta_1 = 0.3464, \quad \eta_2 = 0.7401 \quad \text{and} \quad \eta = 54.32\%$$

iii . Grouping efficacy:

$$\phi = 53 \div 106 = 0.5 \quad \phi = 100 \div 106 = 0.9433$$

$$\tau = 0.257$$

iv. Grouping measure:

Machine utilization index, $\eta_g = \eta_u - \eta_m$

$$\text{where } \eta_u = e_d / e_{d+v} = 53 / (53+100) = 0.346$$

$$\eta_m = 1 - e_{d/o} = 1 - 53/106 = 0.5$$

$$\text{Therefore } \eta_g = - 0.154$$

(η_g value lies between -1 to 1 and η_u, η_m values lie between 0 and 1)

v . Grouping capability index (GCI):

$$GCI = 1 - e_{j/o} = 1 - 53/106 = 0.5$$

vi. Grouping index (GI):

Assuming $q=0.5,$ $\alpha = 0.5,$
 $\gamma = 0.333$

The comparison of results is done in the following section.

Table 3. The results obtained for existing and due to proposed solution

S. no.	Performance measure	Values for functional layout.	Values due to proposed solution.
1	Number of exceptional elements.	53	04
2	i. Within group utilization. ii. Inter cell movement of the parts. iii. Grouping efficiency.	$\eta_1 = 0.3464$ $\eta_2 = 0.7401$ $\eta = 54.32\%$	$\eta_1 = 0.33$ $\eta_2 = 0.921$ $\eta = 62.7\%$
3	Grouping efficacy.	0.257	0.4194
4	Grouping measure ,(GM).	- 0.154	0.2977
5	Grouping capability index,(GCI).	0.5	0.9623
6	Grouping index ,(GI).	0.333	0.4927

COMPARISON OF RESULTS

The results obtained on performance evaluation in case of existing layout of 'M/s Kinetic gears' and modified solution is given in Table 3.

CONCLUSIONS

The results obtained in the previous section clearly show the scope of improvement is possible due to proposed method of machine-component grouping. In summarised way it is concluded that,

- I. Performance measure 1 entail much reduction in the intercellular movements can be achieved through reduction of 'EE'.
- II. Performance measure 2 shows the machine utilization shall remain same but remarkable improvement in intercellular movements can be made. This leads to increase in grouping efficiency amazingly.
- III. Much improvement is seen in grouping efficacy as indicated by performance measure 3.
- IV. Grouping capability index (GCI), Grouping measure (GM), Grouping index (GI) have improved in the modified solution.
- V. Due to dissimilar processing requirements of parts the case is involved with large number of exceptional parts.
- VI. Due to large exceptional parts the precise grouping of machine and components is possible to a smaller extent as expected.
- VII. The method clusters the machine components well in case of situation involving large exceptions also as indicated via improved values of efficiencies and performance measures.

RECOMMENDATIONS

It is recommended that the present machine arrangement tends to increase the intercellular movements that is manual transportation of parts impair the overall efficiency and in view of reducing them the machines are parts must be as close as possible i.e. parts need to be manufactured in single unit due to diverse processing requirements as suggested via modified solution in Fig. 3. The machines can be physically arranged as

suggested via modified solution in Fig. 3 for improving the productivity.

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